X-320-64-361

NASA TMX-55120

EXPERIENCES IN SIMULATING THE SPACE ENVIRONMENT FOR SCIENTIFIC SATELLITES

JULY 1964

GODDARD SPACE FLIGHT CENTER

GREENBELT, MARYLAND

Copy No.

EXPERIENCES IN SIMULATING THE SPACE ENVIRONMENT FOR SCIENTIFIC SATELLITES

July 1964

TEST AND EVALUATION DIVISION
OFFICE OF TECHNICAL SERVICES

EXPERIENCES IN SIMULATING THE SPACE ENVIRONMENT FOR SCIENTIFIC SATELLITES

by

John C. New
Goddard Space Flight Center

SUMMARY

~~15509~~

The Goddard Space Flight Center, NASA, has carefully analyzed its efforts to recreate the space environment under laboratory restraints. Conclusive evidence shows that such a complex goal are measurable in both newly developed technological skills and highly sophisticated space environmental simulators. Even so, experience has shown that the exact duplication of the space environment is beyond the realm of what is considered feasible. Therefore the whole gamut of spacecraft testing resolves itself in simulated space environmental testing. This test mode has been highly effective in detecting deficiencies that demand corrective action for mission success.

Author

CONTENTS

		Page
	Summary	ii
1.	INTRODUCTION	1
2.	THE SCIENTIFIC SPACECRAFT	2
3.	THE SPACECRAFT ENVIRONMENT AND ITS SIMULATION	2
4.	TEST AND EVALUATION PHILOSOPHY	3
5.	RESULTS FROM SPACE ENVIRONMENT SIMULATION	4
6.	SPACE RESULTS	4
7.	ORBITAL SIMULATION TESTS	4
8.	LIFE TESTS	6
9.	CONCLUSION	7
	Acknowledgement	8
	References	8
	Illustrations and Tables	9
	List of Illustrations and Tables	10

EXPERIENCES IN SIMULATING THE SPACE ENVIRONMENT FOR SCIENTIFIC SATELLITES

by

John C. New
Goddard Space Flight Center

1. INTRODUCTION

The American space program, which is devoted to the peaceful exploration of space for the benefit of all mankind, is under the direction of the National Aeronautics and Space Administration, NASA. The magnitude of this program is roughly $5 billion annually, or about 1% of the Gross National Product of the U.S. NASA's program comprises four main areas: (a) Advanced Research and Technology, (b) Manned Space Flight, (c) Space Sciences, (d) Application of earth satellites to communications and meteorology.

The Goddard Space Flight Center, a key element in NASA, is the first major United States laboratory devoted entirely to the investigation and exploration of space with unmanned space vehicles. Established in 1959, the Center was named after America's rocket pioneer, Dr. Robert H. Goddard. Most of the 3600 employees of Goddard occupy new building on a 600 acre site in Greenbelt, Maryland, a Washington, D. C. suburb. The laboratory currently represents an investment of over $60 million in structures and equipment. Its employees are responsible for investing about $1 million per day on some 30 major projects running the gamut of space exploration and technology.

The Center is responsible for complete development of unmanned sounding and earth-orbiting spacecraft experiments in basic and applied science covering three scientific areas: communications, weather observations, and advanced scientific technology. Goddard also manages the development and launch of NASA's Delta rocket, and launches Centaur and Atlas-Agena rockets on behalf of other members of the NASA family. The Center directs two world-wide satellite tracking, data acquisition, and data reduction networks. These are the Space Tracking and Data Acquisition Network (STADAN) and the Manned Space Flight Network (MSFN).

Due to the extremely varied and complex projects under its direction, Goddard has developed an unusually wide range of talents and capabilities. It is in fact one of the few installations in the world capable of conducting a full-range space science experimentation program. This involves carrying a concept through theoretical work to experimental design and engineering. . . .to payload fabrication and

The author presented this paper at the First International Congress on Vacuum Techniques in Space Research, July 1, 1964, Paris, France.

assembly. . . .to complete test and evaluation program. . . .to rocket launch and satellite tracking, data acquisition, and data reduction. Figure 1 shows a time scale for these various functions.

2. THE SCIENTIFIC SPACECRAFT

The scientific spacecraft is a complex, highly sophisticated research instrument for mapping the frontiers of outer space and relating these properties to life on earth. Such spacecraft or satellites (these terms are used interchangeably) vary from the very simple single experiment type to the very complex orbiting scientific observatory. While such spacecraft can weigh up to several thousand pounds, experience to date has been primarily with Delta-size spacecraft weighing less than 500 lbs. The average weight has been near 160 lbs. and the maximum dimension (without solar paddles) has been usually less than one meter. A scientific satellite is predominately electronic in nature and might include 1000 transistors, 1500 diodes, 5000 passive components (resistors, capacitors) and 8000 solar cells. It often contains mechanical devices which erect antennas, solar paddles or experiments in space. Other major subsystems and the weight distribution will be found in Figure 2.

A scientific spacecraft launched by a Delta vehicle is not inexpensive. The total investment in the space system up to the point of launch, including the research and development labor, the spacecraft flight units and prototype design models and the launch vehicle approaches $10,000,000. As a very gross estimate the division of costs is roughly one-third each between labor, space hardware, and launch vehicle. With an investment this large it is prudent to spend ten or twenty percent in assuring that the spacecraft is flight worthy and will indeed yield usable information when operating in the space environment. To accomplish such test and evaluation objectives one must understand the space environment, develop a test philosophy, and establish adequate simulation facilities.

3. THE SPACECRAFT ENVIRONMENT AND ITS SIMULATION

A spacecraft, depending upon its mission, experiences several different environments during its life history. A broad classification of these would be (a) pre-launch, (b) launch, (c) orbit, (d) re-entry, and (e) planetary dwell. There are many subdivisions of these broad categories as shown in Figure 3.

The pre-launch environment in general is controllable and well understood, the launch environment is more variable but lends itself to statistical prediction. It is often bounded in an upper limit by some relationship to the launch vehicle thrust and dynamic characteristics. The orbital and planetary environments are definable with the least confidence. Often we have only a scientific prediction based upon very gross or indirect measurements. Certainly our scientific satellites are improving these predictions and adding confidence at a rapid rate. Some limiting factors in duplicating some of the critical knowledge of the total environment and its effects on complete systems, together with the economics of the reproduction, are the key problems.

4. TEST AND EVALUATION PHILOSOPHY

In evaluating a spacecraft it would be ideal if the space environment could be reproduced exactly. Economic, technological and terrestrial limitations prevent achievement of this ideal objective. One must then devise a philosophy of testing which accommodates these restraints and achieves a high degree of assurances that the spacecraft will be successful.

At the Goddard Space Flight Center our philosophy has been to concentrate on *total systems testing* under environmentally induced stress levels for sufficient time that most deficiencies will be manifested in a detectable manner. A prototype system is tested at augmented stress levels and durations (launch environments only) to qualify a given design. The actual flight systems are tested at environmental stress levels which would not be expected to be exceeded more than once in twenty cases. (See Figure 4). For design qualification tests on prototypes, it is customary to increase vibration amplitudes by 50% and durations twice that expected during launch. Predicted temperature extremes are extended 10° C to provide a margin. Vacuum simulation is of the order of 10^{-5} torr and is often 10^{-8} torr. Space chamber walls are black with an absorptance of better than 0.90 and are at near liquid nitrogen temperatures of about 30°K for economic reasons.

Since duplication of the planned orbital life (one year) is not economically feasible, the duration of the orbital tests is limited to that time (5 to 10 days) whereby those failures attributable to "infant mortality" can be detected and corrected. Such tests include temperature extremes, solar simulation, spacecraft positioning for various orbital conditions, and operation of the complete system in all modes of transmission. The operating time accumulated on a flight unit before launch ranges between 600 and 1200 hours. A graphical representation of this philosophy is shown in Figure 5.

The hypothetical graphs shown in Figures 4 and 5 are given some credence when one compares the actual data for a very recent major spacecraft shown in Figure 6. The validity of the Goddard test philosophy is attested by the fact that 16 prototype and 48 flight units have been evaluated. A total of 855 problems have been uncovered and corrected resulting in *27 successful satellites* or probes and only one major failure—Syncom 1—in a five year period. Ten of these satellites were designed, developed and tested at Goddard whereas 18 of them were under Goddard management but the actual design, development and tests were conducted by prime contractors. The remaining discussion of this paper will be restricted to activities at the Goddard Space Flight Center and more specifically the spacecraft projects as shown in Figure 7. As shown, the environmental test programs can extend over several years (S-6) or be very short (less than one month) (Note S-3b) depending upon previous history. A two month period is more typical for flight units. The test and evaluation effort varies from about 15 to 30% of the total project effort through launch activities. A most important by-product of the philosophy of complete systems testing is the training of the launch crew which operates the spacecraft throughout the integration, test and launch phases.

5. RESULTS FROM SPACE ENVIRONMENT SIMULATION

A review of the problems encountered in testing the aforementioned spacecraft reveals that for prototype units an average of 31.4 problems were encountered versus 6.0 for flight units. A problem is defined as any deviation from expected performance which causes rework or delay in the qualification or acceptance testing of the spacecraft. The five to one ratio from prototype to flight unit indicates a high learning ratio. It further underscores the importance of testing a complete working system as early in the project development cycle as possible. Figure 8 shows the structural dynamic environment uncovers about 1/5 of the problems, the thermodynamic environment accounts for about 1/2 of them and functional performance testing accounts for about 1/4. Figure 9 shows the distribution of problems per spacecraft by subsystem. As one might expect by the advanced nature of the scientific experimentation aboard a spacecraft, this subsystem accounts for the largest number of problems. By way of explanation the "Other" classification primarily includes wiring harnesses and connectors. It is not surprising that this interface hardware—the last item to be designed and often changed or modified at the last minute—is the second most prevalent source of problems.

6. SPACE RESULTS

It is difficult to make specific comparison between laboratory simulation tests and results in space. In general, it can be stated that all these satellites have provided useful scientific data, and have continued to operate from a few months to several hundred days. Failures in space have been attributed most frequently to deterioration of the power supply or associated electronics. It is possible to draw some comparison in temperature data for selected subsystems as shown in Table II. There are several local anomalies and spacecraft external subsystems which show greater divergence. In general there are known causes for these variations from test limits which offer satisfactory understanding. These have to do with α/ϵ values for coatings, post-test changes in experiments, and complete understanding of the thermal analysis and design in setting test temperature limits. As an example, a post-test change of one experiment reduced the average orbital temperature of the spacecraft by 5° C. Problems of this type are more complex with surface mounted items which may require special coatings with α/ϵ ratios different from the main spacecraft and which do not benefit from the thermal inertia of interior mounted components.

7. ORBITAL SIMULATION TESTS

Table III is a summary of all orbital simulation tests performed at Goddard. It shows that about 75% of the time has been spent in a thermal-vacuum soak test at either a hot or cold extreme. Less than 10% of the test time has been in solar simulation. The average time for prototype units per spacecraft has been 300 hours or 12½ days. Flight units have averaged about one-half this time.

The facilities for *space vacuum* simulation have been constantly improving at a rate of about one decade per year. It is not uncommon to find large space chambers operating on the 10^{-10} torr range without the spacecraft. Depending upon the spacecraft, test temperature and chamber pumping capacity this pressure may increase two or more decades. Outgassing rates on typical Delta-size spacecraft have been measured after twenty-four hours of exposure to vacuums in the 10^{-6} torr range. When the exposure is at a temperature of −10° C the rate lies between 15 and 40 micron-liters per second. When the exposure is at +55° C the rate may be as high as 70 micron-liters per second.

In the *thermal-vacuum soak test* the walls of the chamber are brought to a predetermined hot or cold limit. A vacuum of 10^{-6} torr or better is produced to assure that the heat transfer is by a radiative process. After the spacecraft has achieved thermal stability with power-off it is cycled through all phases of its functional performance. The thermal time constant of a spacecraft may be defined as the time required for a temperature difference to be reduced to 1/e of its original value, then the time constant for a typical Delta-size spacecraft has been determined as 18 hours in the vacuum environment. Uniform soak testing of the type described is predicated on the assumption that the thermal design and orbit prediction is correct. This test is therefore a demonstration of the functional capability among the subsystems at extreme temperatures under vacuum. Care must be exercised in this test. The upper and lower soak temperature is based on the maximum and minimum orbital predicted power-off temperature for the spacecraft. The value given is thus in *average* maximum and *average* minimum temperature for the bulk of the spacecraft. External experiments or near surface units are not stressed to the expected limit for a given orbit. They can be tested separately over a broader temperature range but this approach invalidated the systems integrity.

Thermal gradient testing allows individual parts of the system to be preferentially heated or cooled. This can be very complex when interior subsystems dissipating appreciable power are involved. Also when the transient response is very rapid control of this type test is most complex.

Solar simulation testing would appear to offer a solution to these complexities. Certainly the thermal balance of the spacecraft can be demonstrated for both the steady state and transient conditions. This test will exercise the α/ϵ property of the coatings as in space provided a proper spectral match is achieved. The key variables in direct solar testing are spectral distribution of the incoming radiation, it's intensity and uniformity. In certain instances, collimation is a key variable. Cold wall simulation is less of a variable for spacecraft operating near room temperature than the other parameters listed. (So long as it is, in fact, nearly black and it's temperature is near 100° K or less). It becomes more of a key variable as the temperature of the spacecraft approaches colder limits of operation. The reasoning for the lack of one to one correspondence is related primarily to spectrum and intensity variability, as compared to the actual sun. The fact that albedo and infrared simulation is most often not introduced, further limits the simulator from producing exact correspondence.

The key in solar testing is to monitor precisely the variable parameters and introduce these parameters into the same computer program used for the space condition. Corrected α/ϵ and intensity in the computer program will permit prediction of the temperature distribution that the spacecraft should attain in the chamber.

Any disagreement between predict and actual test is therefore a function of the thermal design or the facility; both of which can be investigated to resolve the disagreement. Where reliable means are used to detect the energy input to the spacecraft, the problem reduces itself to the thermal design. Once thermal design is proven, the problem of conditioning to create the extremes, and correct gradient are again present. With spin stabilized spacecraft having simple shapes and uniform α/ϵ coated surfaces, the problem is simplified; α/ϵ in the chamber must be determined and the intensity properly adjusted to input an equivalent one sun power level. For most orientations, adjusting the intensity to account for planetary albedo and infrared inputs can be done. For differentially coated spacecraft having earth stabilized reference surfaces, the problem becomes more complex, depending upon the spectral mismatch of the simulator versus the materials being illuminated, and the directional input now required for infrared and albedo. This case can still be handled, however, it is extremely doubtful that any single test would result in simultaneous proof of thermal design and proof of electronic performance and maximum and minimum temperatures for all critical locations in the spacecraft. For this complex case, it may be required that solar and soak or gradient testing be done.

8. LIFE TESTS

One of the least understood phenomenon is that of long term effects in space. The Test and Evaluation Division of the Goddard Space Flight Center is currently preparing to conduct an extended period test in the 30x40 Space Environment Simulator. The test consists of the exposure of the UK-D spacecraft (second flight unit of Ariel II) to a continuous vacuum environment and programmed solar simulation for 60 to 90 days. The test will permit the investigation of an integrated spacecraft under this prolonged exposure and the determination of chamber parameters over an extended period of operation. The task carries the name of Project ASSESS (Active Spacecraft Subjected to Extended Space Simulation.)

The Space Environment Simulator of nearly 50,000 cubic feet volume has a demonstrated vacuum capability on the 10^{-10} torr using mechanical exhaust pumps, oil diffusion pumps and cryogenically cooled walls at both 20° K and 80° K. The solar simulator covers a circle 20 feet in diameter at an intensity of more than one solar constant (130 watts/sq. ft.). The uniformity is better than ± 5% and the collimation angle less than 4°. The light source is a Mercury Xenon 2.5 KW compact arc lamp. One hundred and twenty-seven modules, each having a hexagonal pattern, are fitted together like a honeycomb to give coverage over the entire area.

A cryogenically-cooled gimbal, capable of two degrees of rotational freedom, has been designed for mounting the spacecraft within the chamber. The gimbal is designed to carry a 500 lb. payload and rotate it at speeds up to 50 rpm. It has a clear distance of 20 feet between the main trunions. It also incorporates a "Zero-Q" spacecraft mount intended to thermally isolate the spacecraft from the gimbal system. A slip-ring assembly is used for signal transmission and includes four R.F. rings.

The spacecraft to be tested will be thoroughly checked out prior to test. The spacecraft will be powered and monitored throughout the test to determine any changes due to exposure. Additional vacuum and thermal coating tests are also being prepared to take advantage of this opportunity for an extended exposure.

9. CONCLUSION

15589

The experiences of the Goddard Space Flight Center, NASA, in recreating the space environment under laboratory restraints are discussed. It has been determined that *exact duplication* of the total space environment is neither technically nor economically feasible. However, operation of the complete spacecraft system under simulated space environments has proved highly effective in detecting correctable problems on both prototype and flight units. Satellites tested in this manner have been very successful in space. The limitations in recreating the space environment attaches particular importance to the correct understanding of the technological problems involved not only in the spacecraft but also in the environment simulator. The technical competence of the professional staff is of prime importance.

author

ACKNOWLEDGEMENT

The information presented in this paper represents the contributions of many staff members of the Test and Evaluation Division, Goddard Space Flight Center, NASA, Greenbelt, Maryland, USA. The author would particularly like to acknowledge the contributions and assistances of Messrs. John Boeckel, Raymond Kruger, Henry Maurer, Kenneth Mercy, and Albert Timmins.

REFERENCES

1. NEW, John C. – "Achieving Satellite Reliability Through Environmental Tests," NASA, Technical Note D-1853, July 1963

2. NEW, John C "The 20 Ft. Solar Simulator at the Goddard Space Flight Center," Proceedings, Fifth Annual Symposium on Space Environment Simulation, AEDC, Tullahoma, Tennessee, May 21, 1964

3. KRUGER, Raymond – "Project ASSESS," Internal Memorandum, Goddard Space Flight Center, Greenbelt, Maryland

4. MERCY, Kenneth and TIMMINS, Albert R. – "Past Experience Program," Internal Memorandum, Goddard Space Flight Center, Greenbelt, Maryland

ILLUSTRATIONS
AND
TABLES

LIST OF ILLUSTRATIONS AND TABLES

ILLUSTRATIONS

	Figure No.
Scientific Spacecraft Development Cycle	1
Elements of a Scientific Spacecraft	2
Environmental Conditions Experienced by Space Systems	3
Test Levels	4
Failure Pattern	5
Time Distribution of Major Spacecraft Failures	6
Period for Environmental Test Program	7
Problems per Spacecraft by Environments	8
Problems per Spacecraft by Subsystems	9

TABLES

	Table No.
Factors in Simulating Critical Space Environments	I
Comparison of Temperature Extremes	II
Orbital Simulation Tests	III

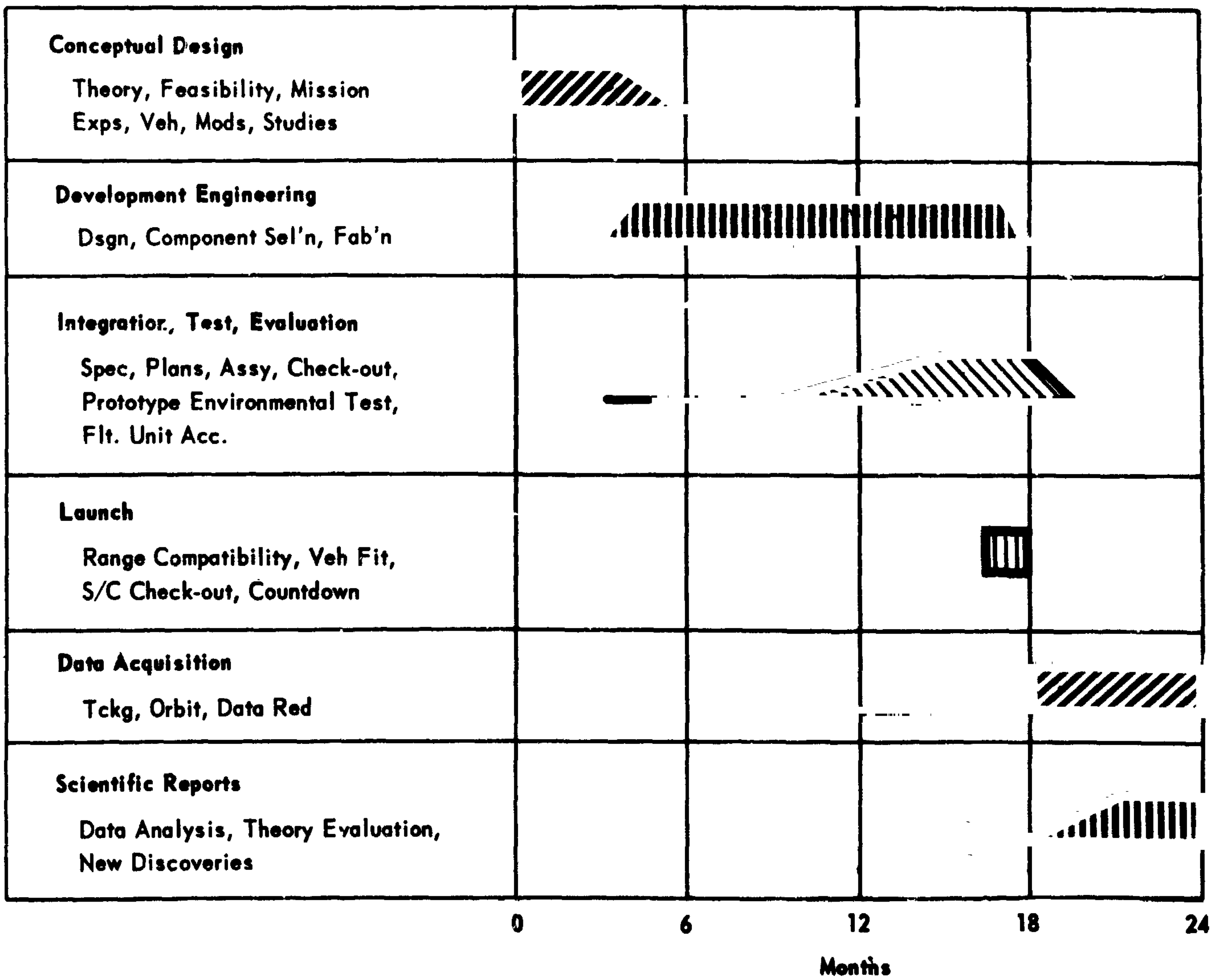


Figure 1. Scientific Spacecraft Development Cycle

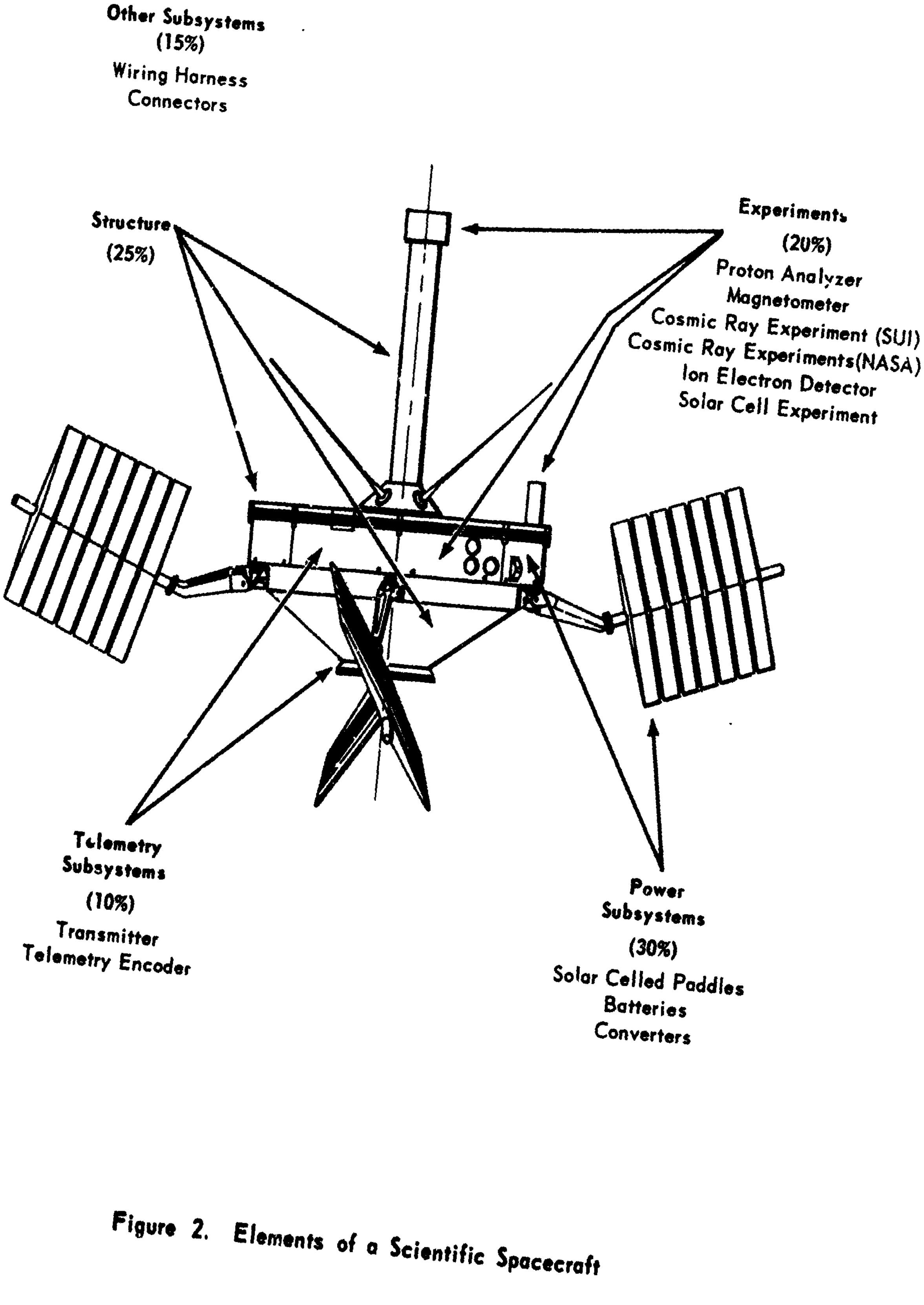
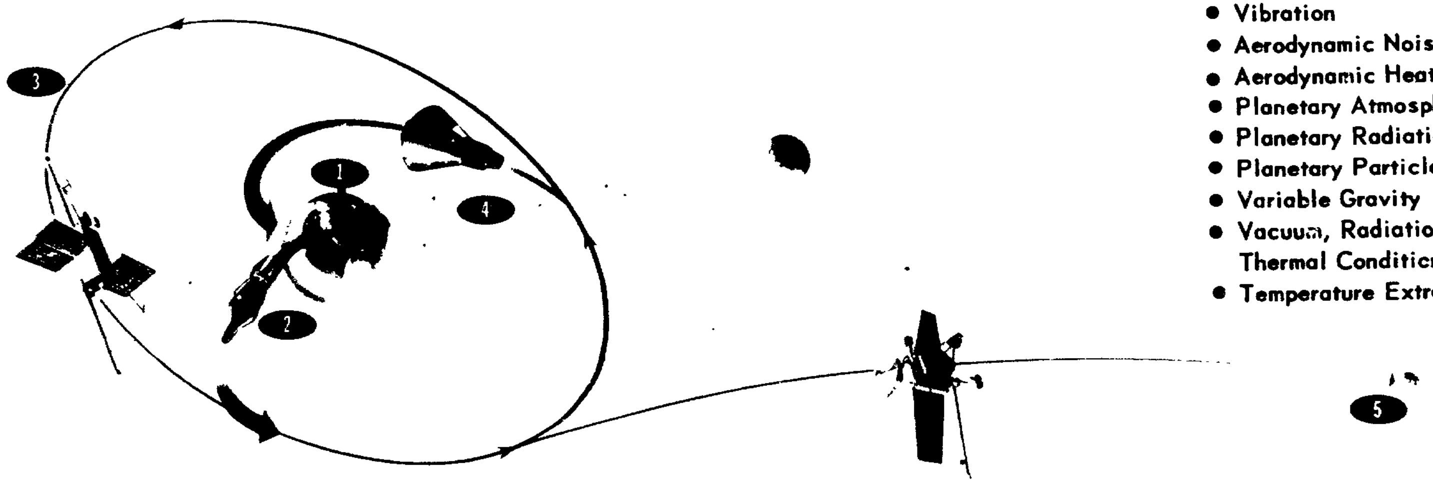


Figure 2. Elements of a Scientific Spacecraft



5

Planetary Landing & Dwell

- Landing Impact
- Vibration
- Aerodynamic Noise
- Aerodynamic Heating
- Planetary Atmospheres
- Planetary Radiation Belts
- Planetary Particles (Dust)
- Variable Gravity
- Vacuum, Radiation, and Thermal Conditions
- Temperature Extremes

1

Pre-Launch Conditions

- Temperature & Humidity
- Shock & Vibration
- Handling
- Sterilization
- R-F Radiation
- Storage Duration

2

Powered Launch

- Shock & Vibration
- Acceleration-Thrust, Guidance, Wind Shear
- Aerodynamic Noise
- Aerodynamic Heating
- Pressure Decrease
- Corona

3

Orbital & Space Flight

- Space Vacuum
- Solar Radiation
- 3°K Heat Sink
- Earth Radiation and Albedo
- Radiation Belt & Solar Flares
- Temperature Extremes, Cyclic Variation
- Separation and Despin
- Weightlessness
- Attitude Control
- Engine Restart, Vibration
- No Air Damping
- Magnetic Torques
- Meteoroids
- On-Board Nuclear Sources

4

Re-Entry Conditions

- Acceleration
- Vibration
- Aerodynamic Noise
- Aerodynamic Heating
- Thermal Shock
- Impact or Landing Shock
- Water Immersion (If Applicable)
- Exposure to Natural Elements Prior to Recovery

Figure 3. Environmental Conditions Experienced by Space Systems

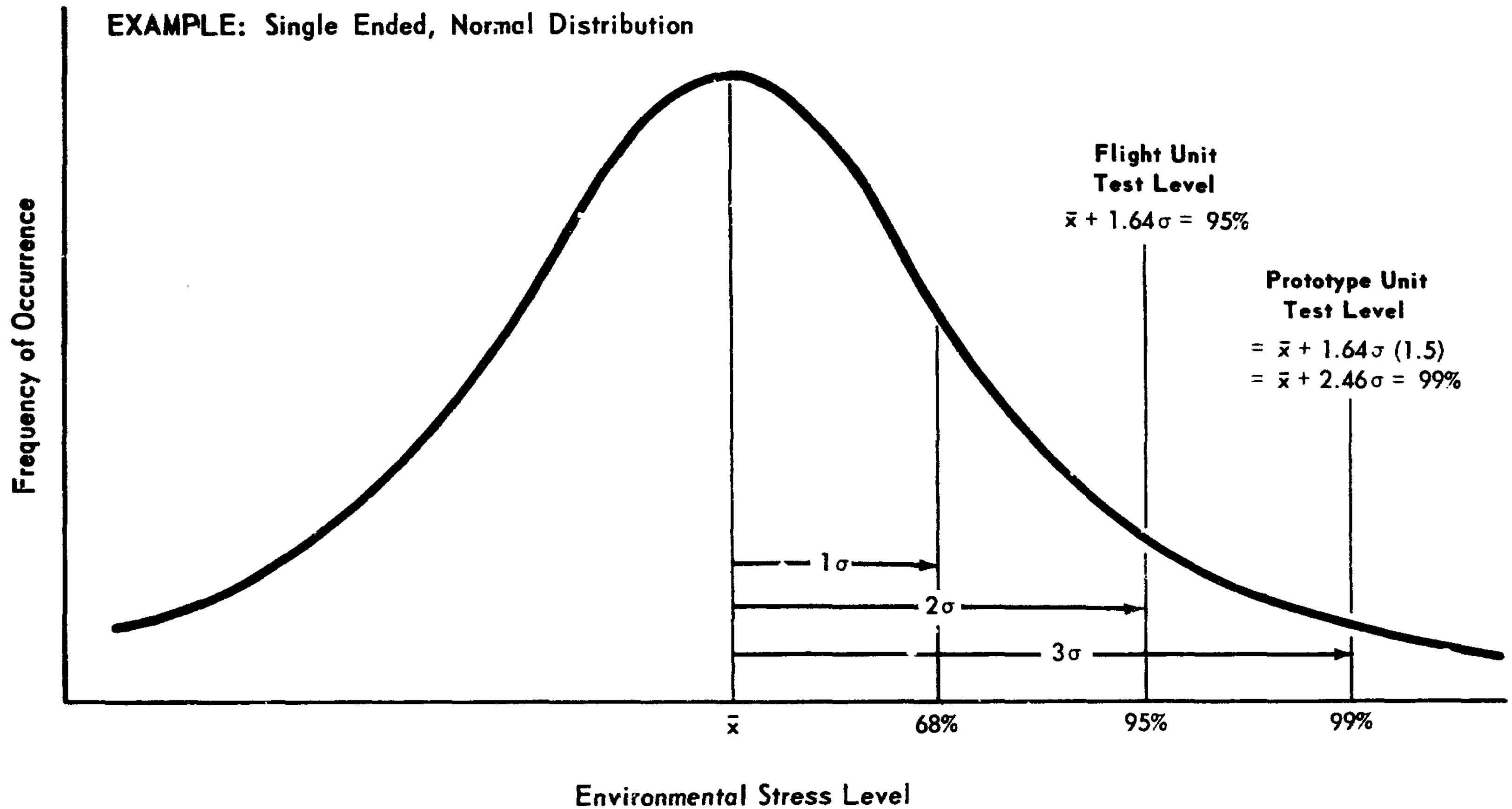


Figure 4. Test Levels

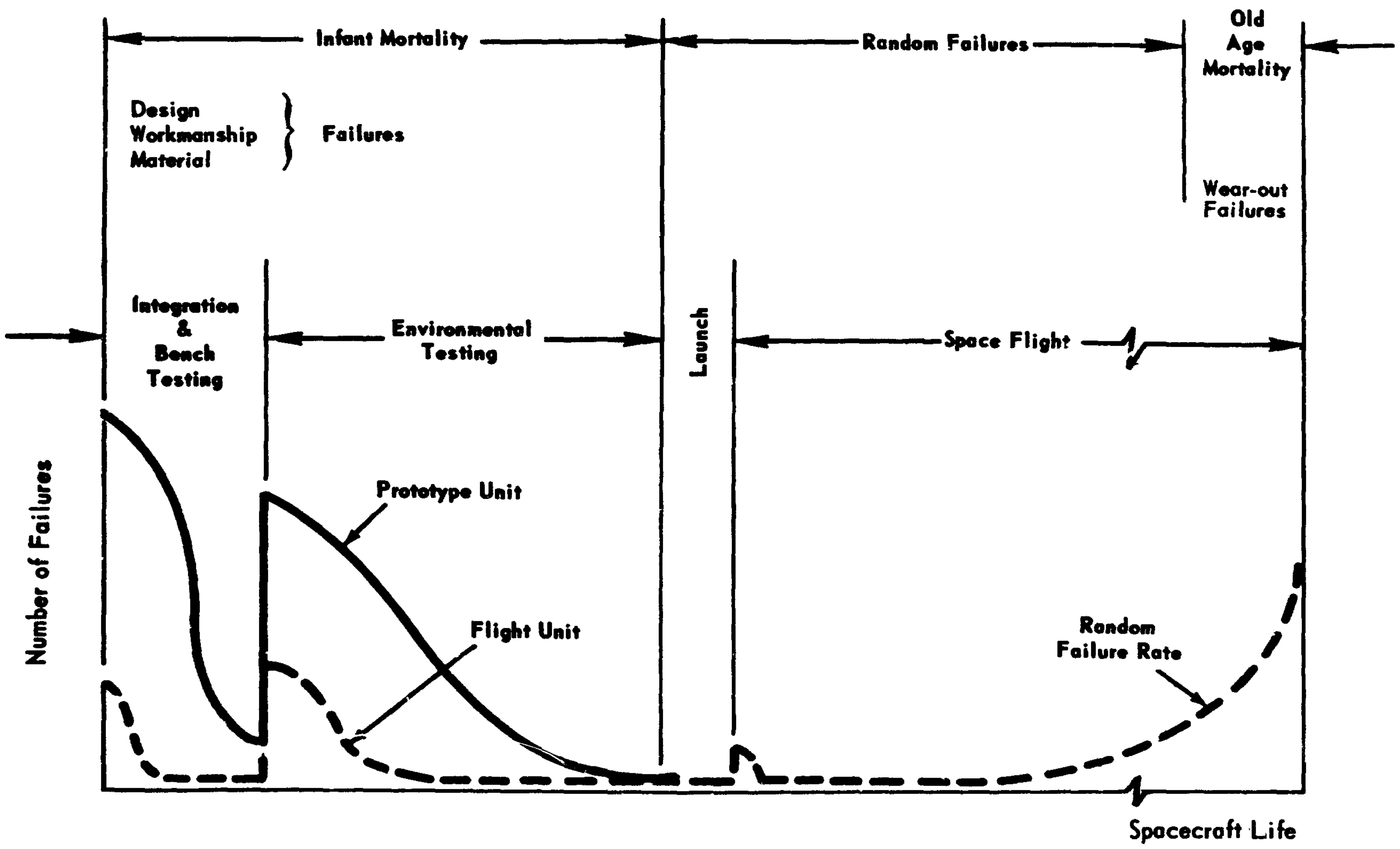


Figure 5. Failure Pattern

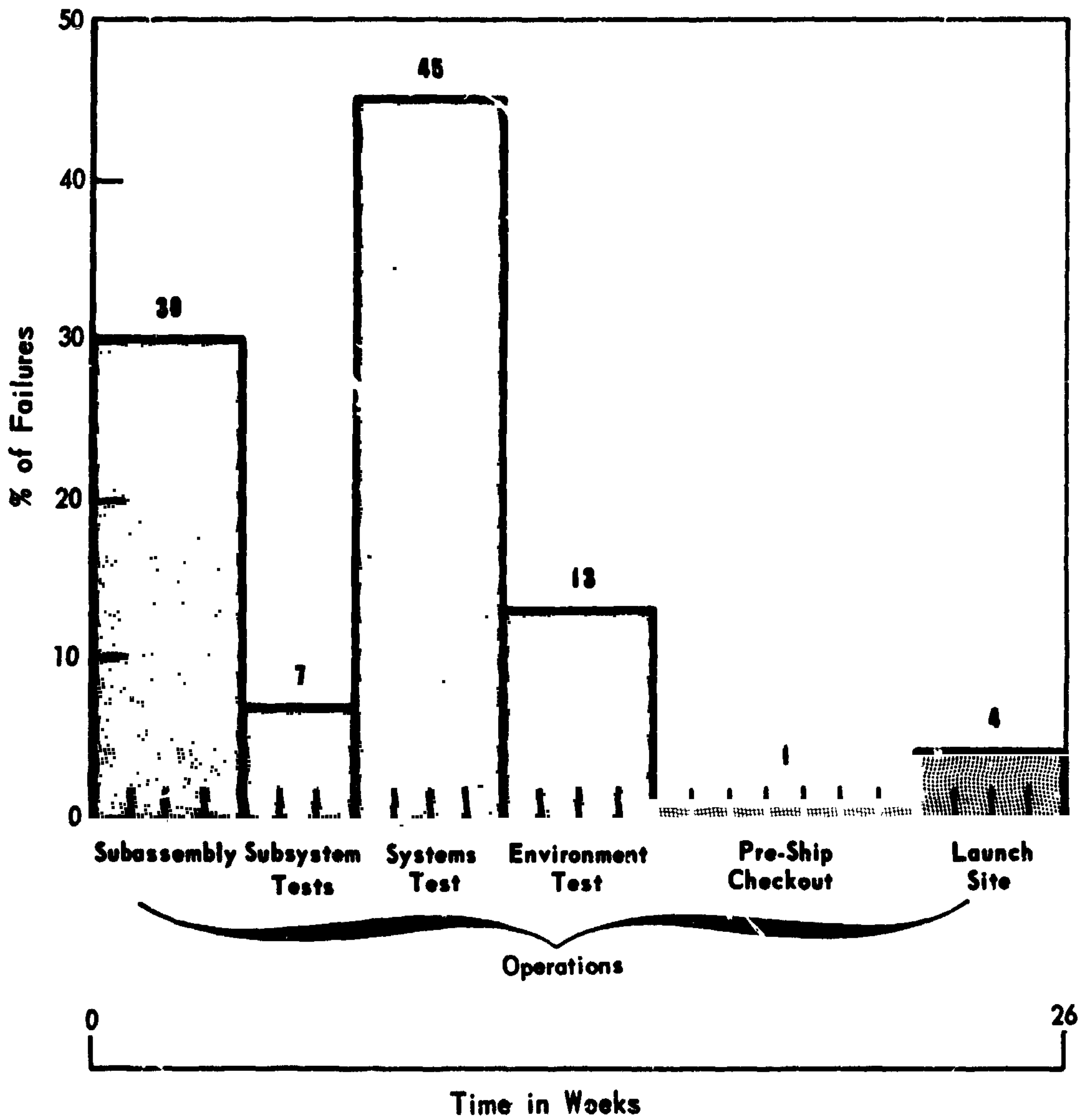


Figure 6. Time Distribution of Major Spacecraft Failures

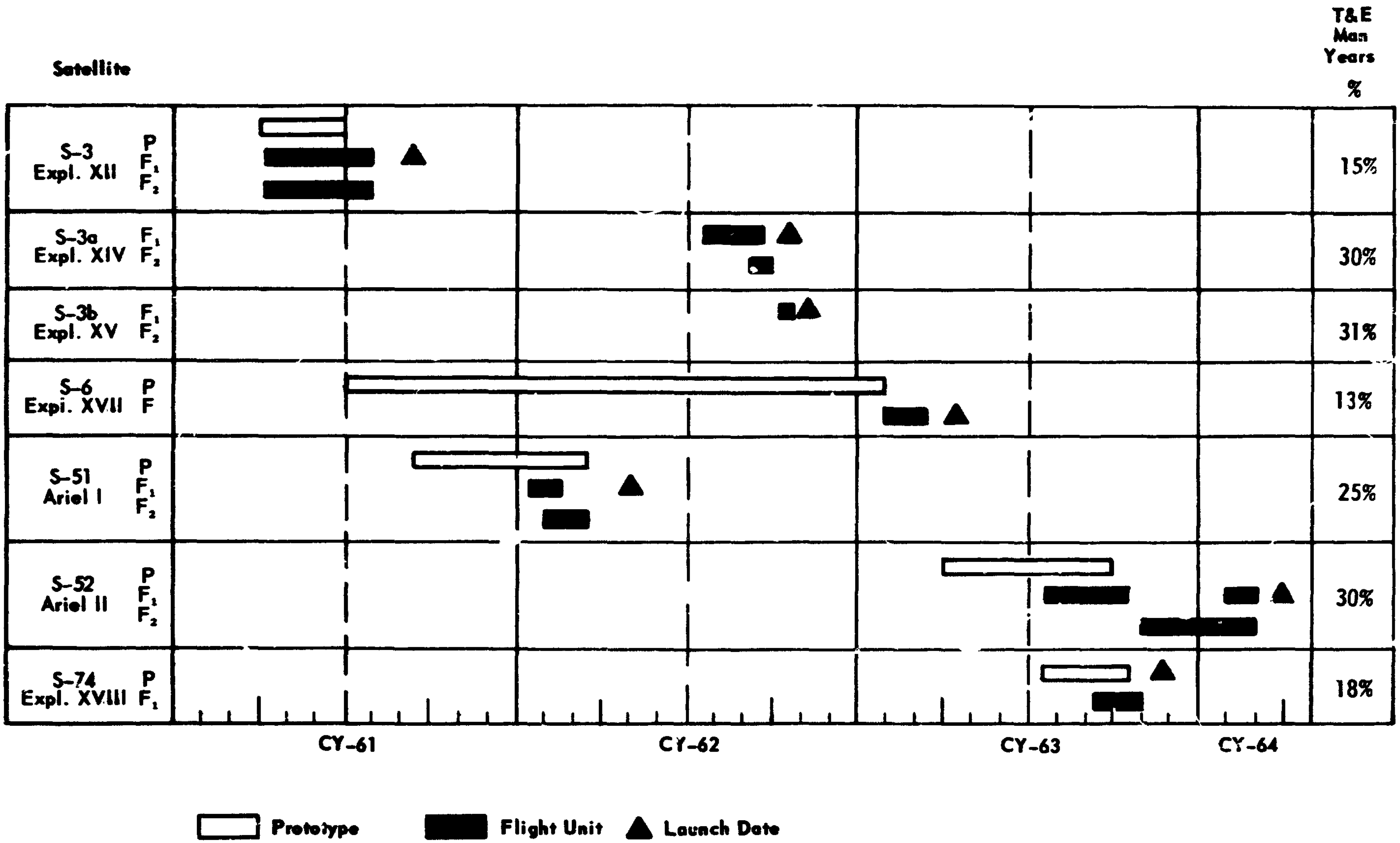


Figure 7. Period for Environmental Test Program

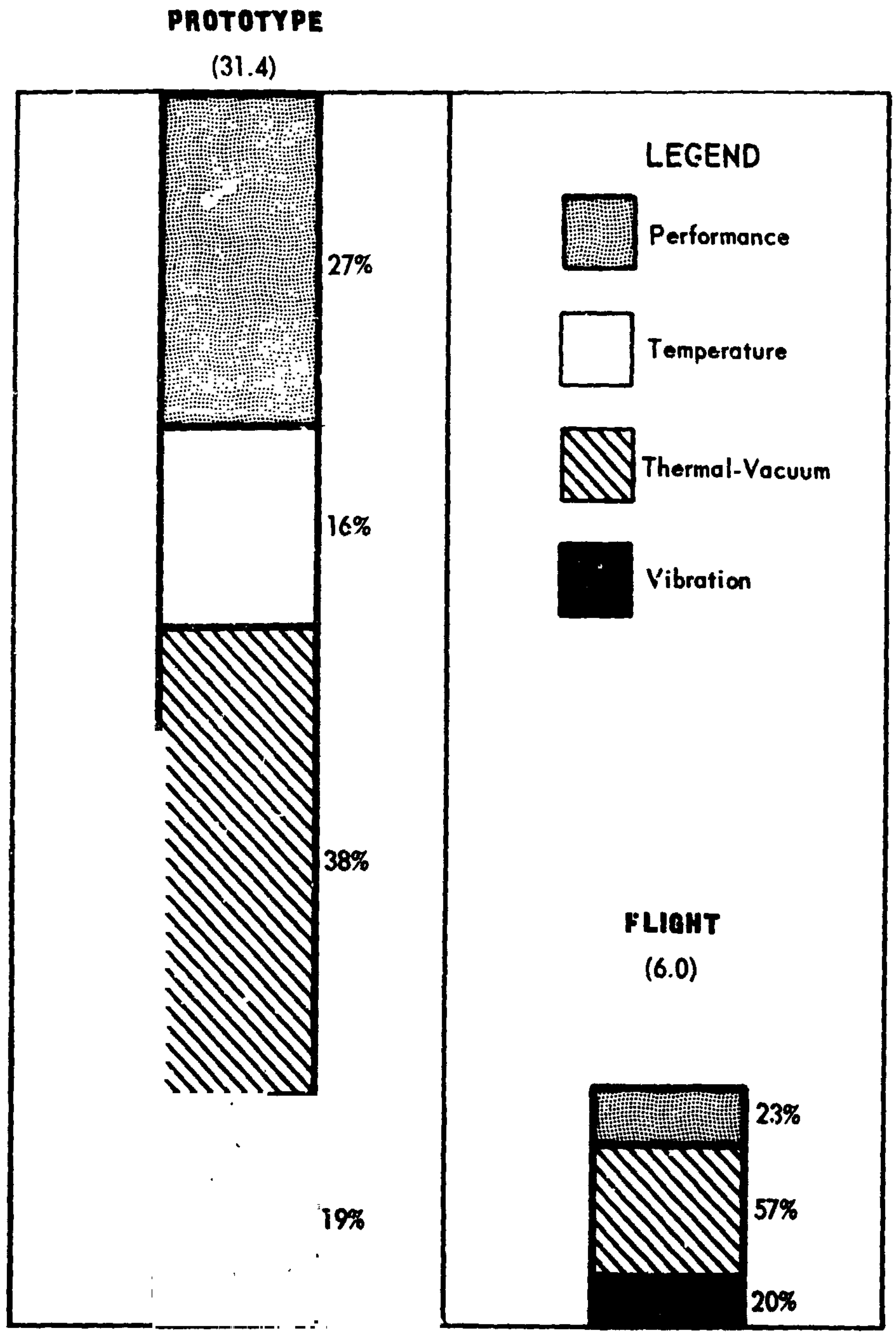


Figure 8. Problems Per Spacecraft by Environments

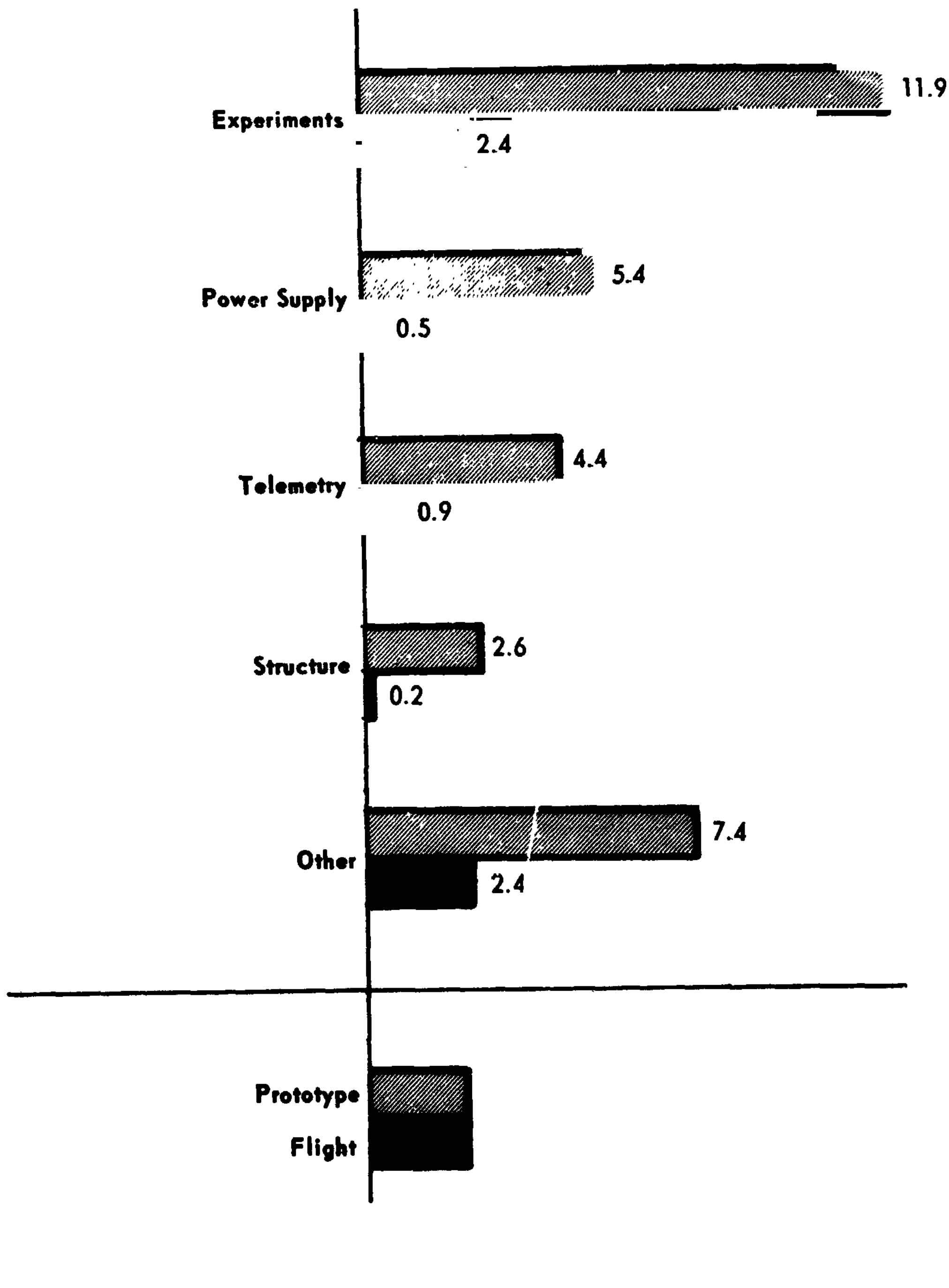


Figure 9. Problems Per Spacecraft by Subsystem

TABLE I

Factors in Simulating Critical Space Environments

Environments	Economic Factors	Technological Factors
1. Launch Dynamics	Acoustic excitation Probability of occurrences	Multi-direction forcing function Synergistic effect of acceleration and vibration Launch vehicle dynamics Impedance match (s/c, shaker, vehicle)
2. Space Vacuum	Ability to maintain large volumes uncontaminated	Ability to reproduce vacuum of space (10^{-14} to 10^{-18} torr) Effects of space vacuum on operating systems
3. Infinite Heat Sink at 4°K	Economics of operation Availability of cryogenic fluids at 20°K & 80°K Size of space chamber	Wall capture coefficients
4. Solar Radiation	Area to be covered Economics of operation	Spectrum, uniformity, collimation match
5. Planetary Albedo & Radiation	Spatial relationship in space chamber to solar sources	Limitation in knowledge
6. Space Radiation	High-energy – heavy particle simulation Limited area of flux	Effects on components and systems Synthesis of radiation spectrum and energy Knowledge of synergistic effects Vacuum mis-match between accelerator and space chamber

TABLE II
Comparison of Temperature Extremes

Spacecraft		Test Temperature, °C		Orbit Temperature, °C	
		Maximum	Minimum	Maximum	Minimum
S-3	(Battery #2)	41	- 5	18	11
S-3a	(Battery A)	35	15	21	19
S-3b	(Transmitter)	47	2	68	32
S-6	(Center Skin)	40	-10	38	- 8
S-51	Battery A	34	- 3	47	23
	Experiment	34	-10	49	- 7
S-52	Battery A	47	-12	49	- 5
S-74	Transmitter	62	21	54	33
	Battery	55	1	52	12
	Experiment	38	- 1	34	15

TABLE III
Orbital Simulation Tests

Type of Test	Prototype (5 units)	Flight (10 units)
Thermal-vacuum (hot/cold)	79%	76%
Thermal Gradient	12%	16%
Solar Simulation	9%	8%
Average Total Time per S/C	300 Hr.	154 Hr.